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(54) Method and apparatus for reducing the peak power of data sequences.

(57) This application concerns the reduction of the peak power of data sequences, particularly for use in a QAM radio relay system. The peak power reduction leads to fewer problems with non-linear distortion, whether caused by the channel, or by the transmitter power amplifier.

The power reduction is achieved by using a shaping code, which replaces sequences with high power, by sequences with lower power.

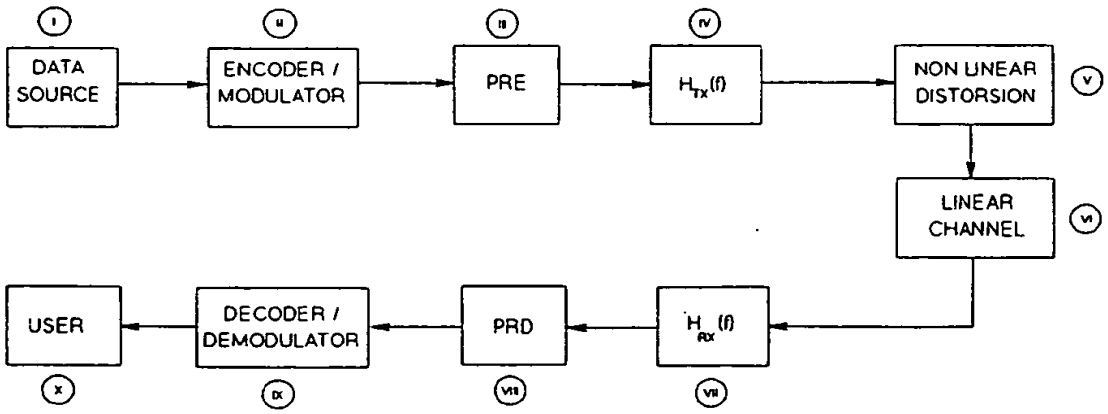

Fig. 1

EP 0 584 534 A1

Background of the invention

The present invention relates to a method of reducing the peak power of the signal at the output of the transmit filter of a digital link, e.g. a microwave one. Such reduction allows to minimize the effects of the transmit channel nonlinearity, including in it eventual nonlinearities of the transmit amplifier.

State of the art

The present digital transmission systems try to obtain high spectral efficiencies through gradually more complex modulation formats. The higher spectral efficiency is counterbalanced by the need of increasing the transmitted power to obtain a prefixed BER (Bit Error Rate: number of wrong bits to total number of bits ratio) value at the receiver. The power delivered by the transmitter generally is limited by the final power amplifier, which has a greatly nonlinear behaviour.
Therefore a serious problem arises with regard to the best exploitation of the nonlinear part of the input-output characteristic of the "channel", including in the latter the final amplifier of the transmitter. At present the problem is faced in one of the following ways (see e.g. the papers of G. Karam, H. Sari, "Analysis of predistortion, equalization and ISI cancellation techniques in digital radio systems with nonlinear transmit amplifier", IEEE Transaction on Communications, vol. 37, n. 12, Dec. 1989):

1) data predistortion: one tries to modify the constellation used for driving the nonlinear amplifier through a signal such as to obtain the desired constellation at its output;

2) analog signal predistortion: a nonlinear circuit having a characteristic opposite to the one of the above-defined "channel", is inserted in the path of the analog signal;

3) channel equalization and nonlinear cancellation of the ISI: the receive equalizer tries to cancel the interferences connected with nonlinearity from the present signal sample (through a suitable nonlinear combination of pre- and post-cursors);

4) use of "circular" constellations so as to reduce the ratio between the peak power and the average power of the not-filtered signal.

All the above solutions, under special circumstances, can provide unsatisfactory features. In particular the first three ones are not much efficient in the presence of hard limiter characteristic of the transmitter final amplifier; the last one gives rise to gains anyway slight which can be not sufficient in case of reception filter with very narrow band.

Summary of the invention

It is an object of the invention to individuate a base-band system which - at parity of other conditions - reduces the peak power of the filtered signal, i.e. at the input of the nonlinear channel defined above.
It has been found, inter alia, that such reduction is to advantage of radio relay systems links, e.g. allowing the use of smaller antennas or the transmission over longer path sections.
The outstanding features of the invention are set forth in the claims while the various aspects and advantages of the invention will become more apparent from the following description (not limiting).

General solution

The basic idea of the invention is based upon the possibility (other conditions such as minimum distance between transmitted points, average transmitted power, etc. being equal) of avoiding transmission of sequences which a high peak power of the filtered signal is associated with, replacing them with more suitable ones (i.e. with a lower peak power of the filtered signal).
The possibility of carrying out this replacement is given by the increasing of the dimension of the alphabet of the transmitted points. In reception the unwanted sequences, suppressed in transmission, are reconstituted in their original form.
By reducing in this way the peak power of the filtered signal it is possible to exploit in a much more efficient manner the nonlinear characteristic of the above-defined "channel".

Fig. 1 illustrates the schematic block diagram of a generic digital transmission system (blocks I, II, IV, V, VI, VII, IX, X) in which blocks II and VIII, subject of this invention, are inserted. In particular, fig. 1 shows:

- the DATA SOURCE (ref. I) which provides the numeric sequence to be transmitted at its output;
- an ENCODER/MODULATOR block (ref. II) which receives at the input the numeric sequence to be transmitted and carries out the standard encoding operations designed for BER reduction (block, convolutional, Trellis Code Modulation, etc., type encoding) and modulation operations, providing at its

output one of the points of the constellation to be transmitted;

- a PRE block (ref. III), subject of the invention along with block VIII, which eliminates from the transmission the unwanted sequences in terms of peak power of the filtered signal, i.e. of the signal at the output of block IV described below;
- the transmission filter HTx (f) (ref. IV) which provides at its output the analog signal to be transmitted;
- a NONLINEAR DISTORTION block (ref. V) representing an unwanted nonlinear distortion on the signal path. It can be due to the nonlinear characteristic of the final amplifier of the transmitter (as it happens e.g. in microwave links) or, more in general, to a nonlinear behaviour of the information channel;
- the information channel proper (ref. VI) identified as "LINEAR CHANNEL", which outputs a signal constituted by the signal at its input added to and/or combined with disturbances of various kind;
- the reception filter HRx (f) (ref. VII) which receives the signal from the transmit channel and carries out a suitable filtering;
- a PRD block (ref. VIII), subject of the invention along with block III, which reconstitutes the signal in its original form containing the unwanted sequences suppressed in transmission by block III;
- a DECODER/DEMODULATOR block (ref. IX) which receives the outgoing signal from block VIII demodulates it and carries out the above-mentioned standard decoding operations, providing the user with the numeric sequence subject of the transmission;
- the USER (ref. X) which receives the numeric sequence.

In an advantageous and therefore preferred embodiment, blocks PRE (III) and PRD (VIII) in accordance with the invention are realized in the form of digital encoders. As an example, fig. 2 shows a block diagram illustrating how it is possible to realize the PRE in case of a radio relay system transmission using a quadrature amplitude modulation (QAM). Let M be the points of the two-dimensional constellation to be transmitted in the conventional case (hereinafter "standard" constellation) and MR be the redundance points necessary for the encoding (carried out in PRE) subject of the invention; the resulting constellation is composed of (M + MR) points (hereinafter "expanded" constellation).

Typically: $1 < (M+MR)/M < 1.2$.

In fig. 2 there is shown the preferred embodiment of PRE; it includes:

- A delay element T (ref. XIII) which receives as its input the last two-dimensional element of the block of N outgoing two-dimensional symbols from XII and outputs it with a delay equal to one channel symbol interval. Such output will be indicated as "state" of the machine in the following.
- A map identified as "(M + MR) MAP" (ref. XI) which receives at its input a block of N symbols of the "standard" constellation and provides (M + MR) blocks of N two-dimensional symbols of the "expanded" constellation. Each output block is relative to a particular "state" of the system and represents the best sequence to be transmitted (in the presence of that particular "state" of the machine) in terms of peak power of the filtered signal.
- A multiplexer "MUX" (ref. XII) having (M + MR) inputs and one output which, on the basis of the "state" at the output of block XIII selects (among the M + MR present at its input) the suitable block of N symbols to be provided at the output.

It remains to be defined what is the meaning of "best sequence in terms of peak power of the filtered signal". According to one particular aspect - even if not limiting - of the invention, the calculation is arranged as follows. Let hTX(t) be the impulse response of the transmission filter IV of fig. 1, T the symbol time, $d^{(k)}$ ($k = 1,2,\ldots, (M+MR)$) the "state" of the system, Ci = (ci, ci + 1, ..., cN-1) the generic block of N two-dimensional symbols, the "weight" w of block Ci = (ci, ci + 1, ..., cN-1) given the state d(k), can be defined as the quantity:

$$w(d^{(k)}, Ci) = \max_{-NT \le t < NT} \left| hTX(to-T)\, d^{(k)} + \sum_{j=0}^{N-1} hTX(to+JT)\, cj \right|^2 \qquad (1)$$

then meaning that the best sequences Ci (in terms of peak power of the filtered signal) are those having a lower "weight" $w(d^{(k)}, Ci)$.

The PRD can be realized through a circuit quite similar to the one shown in fig. 2 for PRE; its description in terms of block diagram (being within the reach of those skilled in the art, in the light of what has been set forth hereinbefore) will be omitted for conciseness' sake.

Reference has been made to specific embodiments represented in figs. 1 and 2 for simplicity and illustrative clearness reasons; therefore it is evident that these are susceptible to those variations, modifications, replacements and the like which, being within the reach of those skilled in the art, naturally

fall within the sphere and the spirit of the scope of the invention.
The following possible variants are here mentioned by way of an example:

- in equation (1) a "state" constituted by several two-dimensional symbols could be envisaged;
- blocks XI and XII of fig. 2 could be replaced by a combinatory algebra, thus transforming the structure of PRE into a convolutional one.
- N could be taken great enough to be able to eliminate in fig. 2 the reaction through block XIII thus transforming the structure of PRE into a "block" structure.

Claims

1. Method of transmitting and receiving numerical signals in which:
   - in transmission, data from a numeric or numerized source are modulated, the modulated signal is filtered and transmitted through a nonlinear channel (where the nonlinearity may be due to the nonlinear characteristic of the final amplifier of the transmitter, or more in general to a nonlinear behaviour of the transmit channel proper),
   - in reception the received signal is filtered and demodulated in order to reconstruct the transmitted numeric sequence

   characterized in that:
   - in transmission, the unwanted sequences in terms of peak power of the filtered signal are eliminated from the modulated signal before filtering and replaced with suitable sequences,
   - in reception, the received and filtered signal is restored in its original form (i.e. containing the unwanted sequences suppressed in transmission) and then sent to the demodulator.

2. Method according to claim 1, characterized in that:
   - the link is a digital, radio relay system link and uses a quadrature amplitude modulation (QAM),
   - the replacement of said sequences is carried out through a base-band digital encoder.

3. Method according to claim 2, characterized in that a "recurring" coding, i.e. using previously transmitted symbols for individuating the symbol to be transmitted, is used.

4. Method according to claim 3, characterized in that the individuation of the sequences to be replaced is carried out on the basis of equation (1) or of relations equivalent thereto.

5. Method substantially as hereinbefore described and represented.

6. System for implementing the method of the preceding claims, including:
   - in transmission, a data source, an encoder/modulator, a transmit filter and a nonlinear amplifier;
   - in reception, a filter and a decoder/demodulator,

   characterized in that:
   - in transmission, an encoder for reducing the peak power of the filtered signal is inserted upstream of the transmit filter,
   - in reception, a decoder for reducing the peak power of the filtered signal is inserted downstream of the receive filter.

7. System according to claim 6, characterized in that the decoder is of "recurrent" type.

8. System according to claim 7, wherein the encoder comprises at least a map and a multiplexer.

9. System according to claim 8, characterized in that the map generates the sequences to be transmitted on the basis of equation (1) or of relations equivalent thereto.

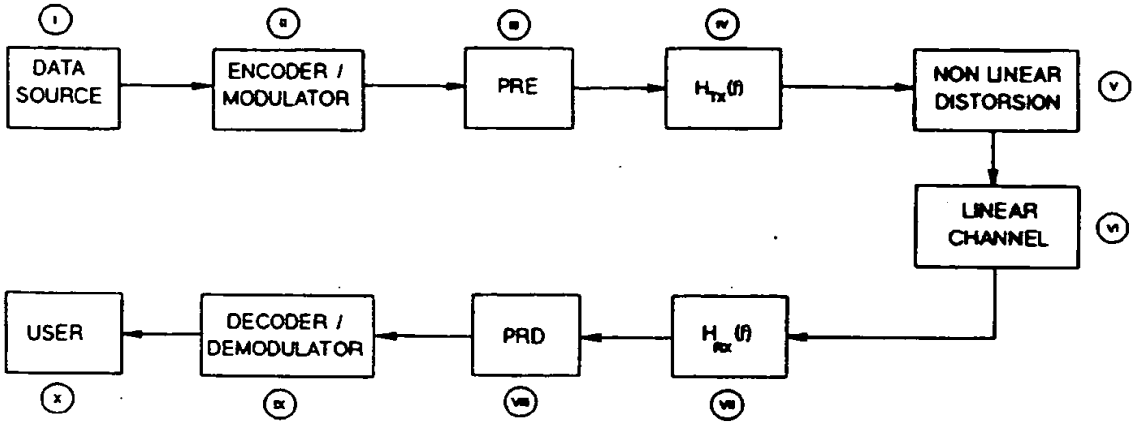
I
DATA SOURCE
II
ENCODER / MODULATOR
III
PRE
IV
$H_{Tx}(f)$
NON LINEAR DISTORSION
V
LINEAR CHANNEL
VI
$H_{Rx}(f)$
VII
PRD
VIII
DECODER / DEMODULATOR
IX
USER
X

Fig. 1

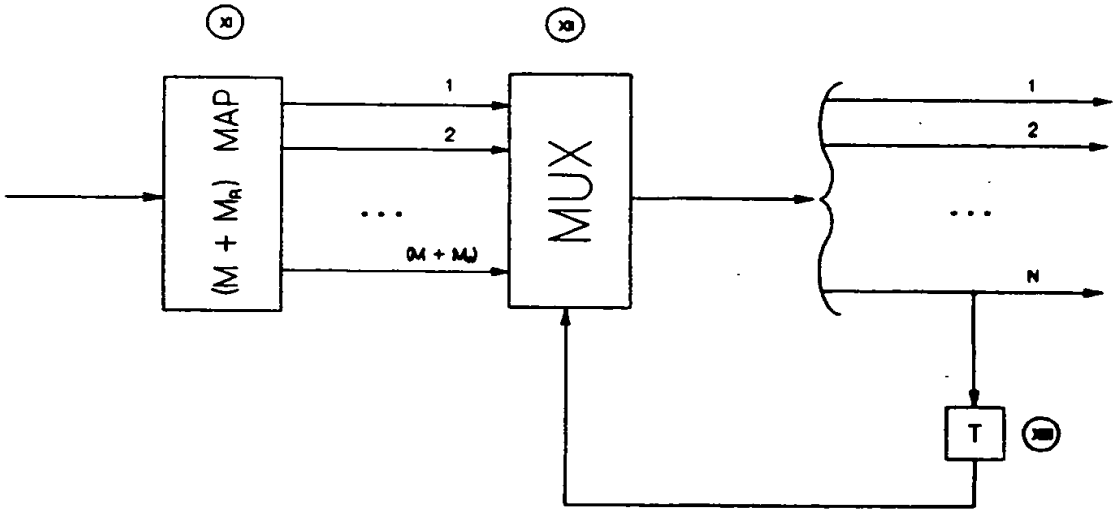
XI
MAP
$(M + M_R)$
XII
1
2
$(M + M_R)$
MUX
1
2
N
T
XIII

Fig. 2

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 93 11 1722

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.5)
X	EP-A-0 383 632 (CODEX) * abstract; figures 1-8,10-13 * * page 2, line 45 - page 3, line 23 *	1-4,6-9	H04L27/34
X	IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATION vol. 7, no. 6 , August 1989 , NEW YORK US pages 941 - 958 FORNEY 'Multidimensional constellations - part II: Voronoi constellations' * abstract; figures 5-7 * * page 950, left column, paragraph 4 - right column, paragraph 3 *	1-4,6-9	
X	TRANSACTIONS OF THE IEICE vol. E71, no. 6 , June 1988 , TOKYO, JP pages 591 - 598 NAKAMURA ET AL. 'A new 90Mbps 68 APSK modem with honeycomb constellation for digital radio relay systems' * figures 11,12 * * page 594, right column, paragraph 3 - page 595, left column, paragraph 2 *	1-4,6-9	TECHNICAL FIELDS SEARCHED (Int.Cl.5) H04L
A	IEEE International Conference on Communications 1991, 23-27/6/1991, Denver, US; IEEE, New York, US, 1991; pages 1075 - 1079, Soleymani & Kang: "Trellis coding with partially overlapped signal sets" * abstract; figures 1,3,4 * * page 1075, right column, paragraph 2 * * page 1077, left column, paragraph 3 - page 1078, left column, paragraph 1 *	1-4,6-9	

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	18 November 1993	SCRIVEN, P

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

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A	IEEE International Conference on Communications 1992; 14-18/6/1992, Chicago, US; IEEE,New York, US, 1992; pages 431 - 1435, Khandani & Kabal: "Using a prefix code for addressing the Voronoi constellations based on lattices Dn and D*n" * abstract; figure 3; table 6 * * page 1432, right column, paragraph 2 - page 1433, left column, paragraph 1 * * page 1433, right column, paragraph 2 - page 1434, right column, paragraph 2 * ---	1-4,6-9	
X,P	WO-A-92 17971 (BRITISH TELECOMMUNICATIONS) * abstract * ---	1-4,6-9	
			TECHNICAL FIELDS SEARCHED (Int.Cl.5)

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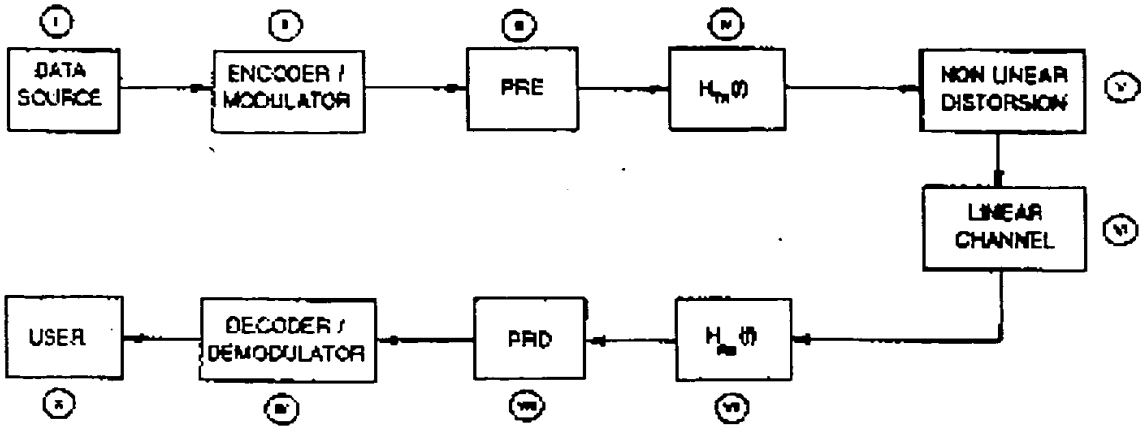
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II
III
IV
DATA SOURCE
ENCODER / MODULATOR
PRE
$H_{Tx}(f)$
NON LINEAR DISTORSION
V
LINEAR CHANNEL
VI
USER
DECODER / DEMODULATOR
PRD
$H_{Rx}(f)$
X
IX
VIII
VII

Fig. 1

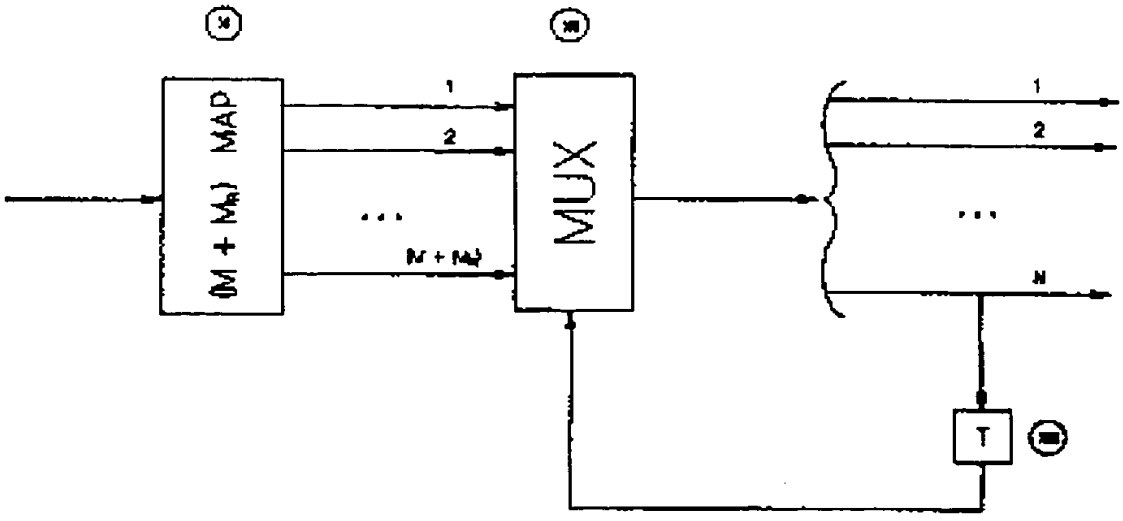
X
XI
MAP
(M + M$_R$)
1
2
...
M + M$_R$
MUX
1
2
...
N
T
XII

Fig. 2